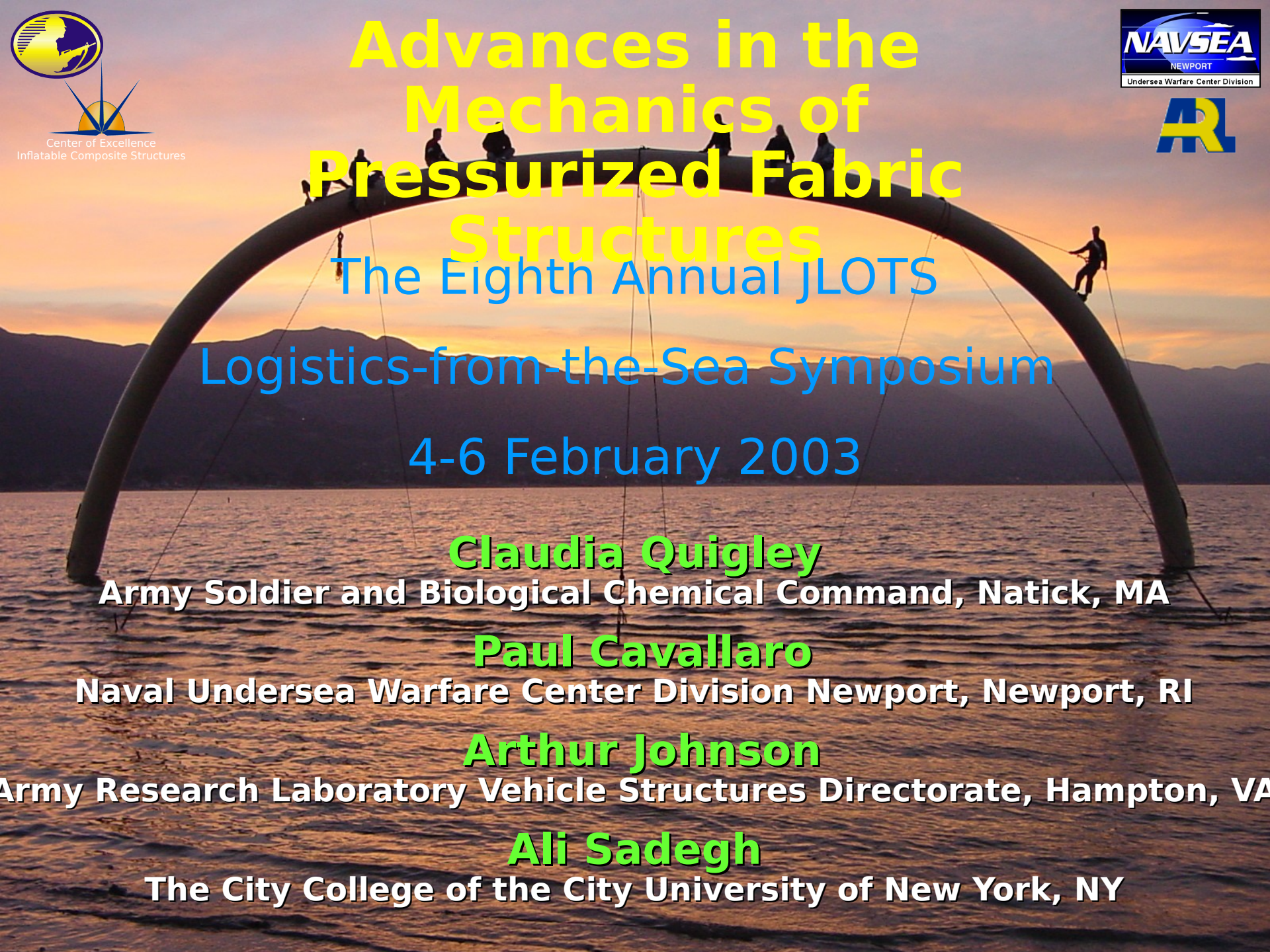

Advances in the Mechanics of Pressurized Fabric Structures

The Eighth Annual JLOTS Logistics-from-the-Sea Symposium

4-6 February 2003

Claudia Quigley
Army Soldier and Biological Chemical Command, Natick, MA

Paul Cavallaro
Naval Undersea Warfare Center Division Newport, Newport, RI

Arthur Johnson
Army Research Laboratory Vehicle Structures Directorate, Hampton, VA

Ali Sadegh
The City College of the City University of New York, NY

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Airbeam Technology

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- Load Bearing Pressurized Fabric Structures
- Pressurization pre-tensions the fibers, creating a structure that is rigid under design loads, but deflects without damage when overloaded.
- Outstanding strength-to-weight is achieved

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Manufacturing Technology

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Braiding Technology

Weaving Technology

- Two new textile technologies produce seamless tubular braided or woven fabrics with high pressure capacity (30-80 psi)
- Curvature and bending resistance are obtained by using coated high-tenacity fibers and controlling fiber orientation.

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Shelter Technology

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- Replace metal structural frame shelters with inflatable arches or “airbeams” to provide:
  - Rapid, Easy Deployment
  - Reduce Weight
  - Low Cube
- Available in widths ranging from 20 feet to 85 feet for applications such as command/control, medical, vehicle/aircraft maintenance

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Dual Use Technology

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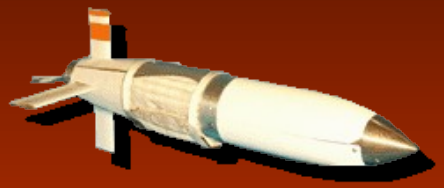
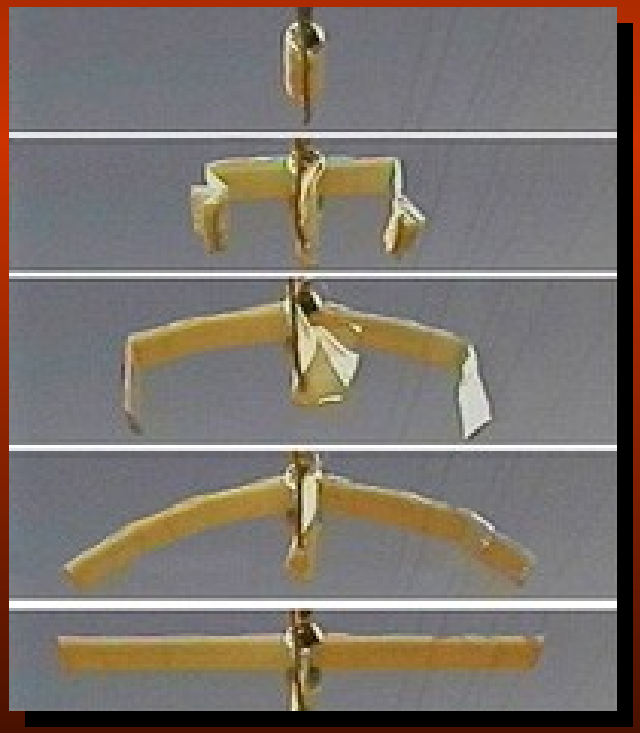


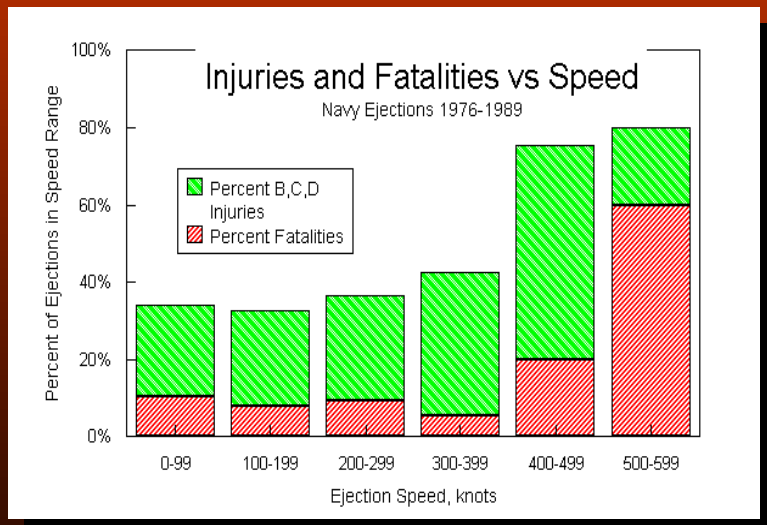


Navy

- Inflatable Wings (Gun Launched Observation Vehicle)
- Inflatable Ejection Seat Stabilizers for Naval Aircraft

Dual Use Technology

Navy Ejection Seat Stabilizers



"A major causal factor of these casualties is the fact that ejection seats are aerodynamically unstable. At high airspeeds this instability causes violent motion and accelerations that can cause both direct and indirect injuries and death."

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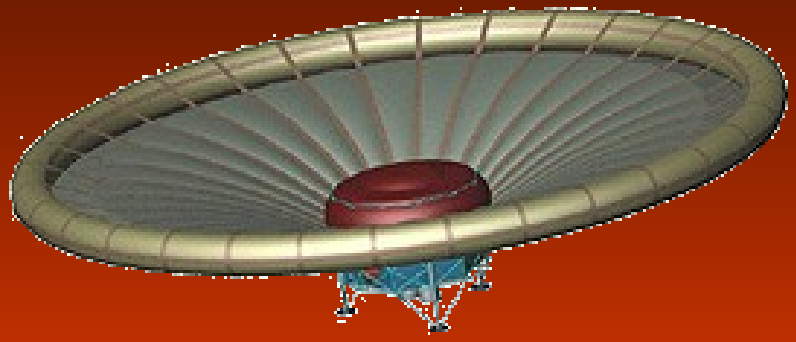

NASA

- **Quickly Deployable Space Structures**

  Mars Lander with Proposed Inflatable Hypersonic Decelerator

- **Inflatable Wheels and Antennas**

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Dual Use Technology

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Lifting 11, 250 lbs.

Army

- Pneumatic Muscle Soft Landing Actuator
- Water and Fuel Containers
- Munitions Barricades

Dual Use Technology

Soft Landing Retractor For Air Drop

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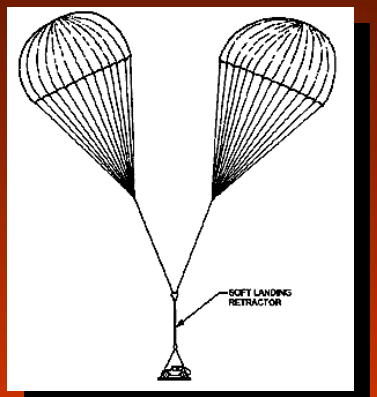
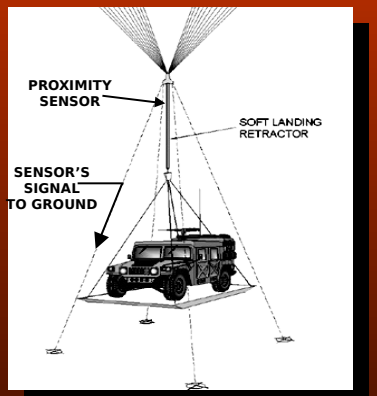
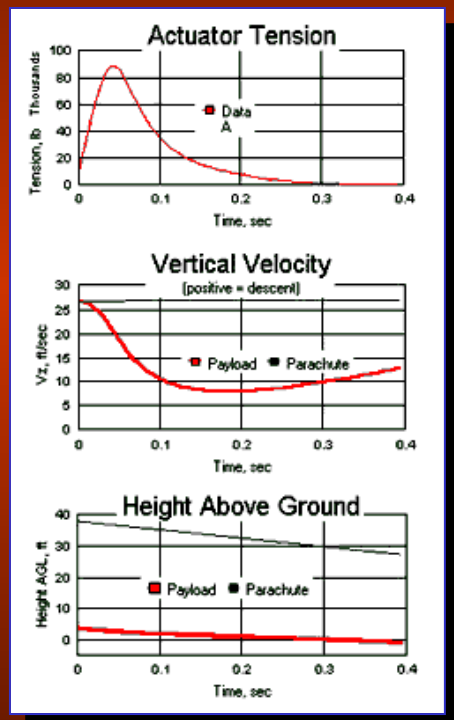


Global View



Local View



PMA Dynamics

How Does It Work?

- Proximity sensor detects prescribed Height-Above-Ground.
- Sensor detonates pyrotechnic charge in retractor.
- Low bias angle fiber placement couples fabric extension with shearing (i.e.; finger trap toy).

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Dual Use Technology

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Army Corps of Engineers

- **Rapidly Installed Breakwater System (RIBS)**

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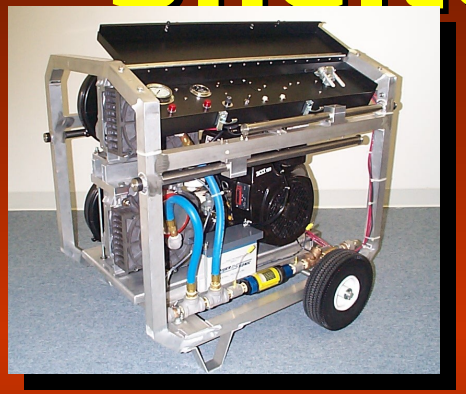
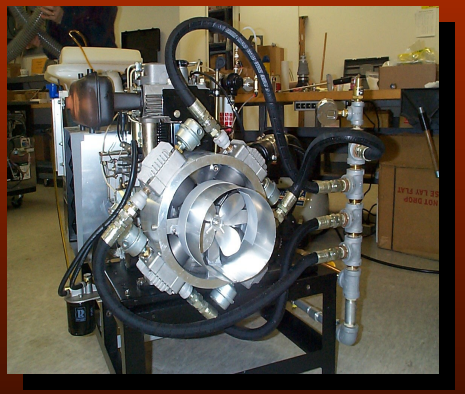
System for Airbeam Shelters

Technologies Explored and Prototyped:

Oil-flooded Screw Compressor



Oil-free Scroll Compressor



Oil-free Wobble Piston Compressor

Objective

Increase capacity, by a factor of five, over commercially available, portable air compressors, through the use of innovative engineering design, lightweight materials, and high-speed components

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(Established in 2001 at the Natick Soldier Center in Natick, MA)

Vision

Deliver new shelter technology into the hands of soldiers and commercial users.

Objectives

- **Refine and optimize inflatable structures technology to Increase durability, reliability and affordability**
- **Establish predictive design tools and models**
- **Broaden inflatable structure applications and commercialize technology**
- **Market and document technology through publications presentations, and meetings with potential users**

VERTIGO INC.

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COLLECTIVE PROTECTION
SHELTERS

Fiber Innovations inc.

Yankee Scientific, Inc.

City College CUNY, NY

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ederal Fabrics-Fibers, Inc.

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Airbeam Technology
How the Pieces Fit

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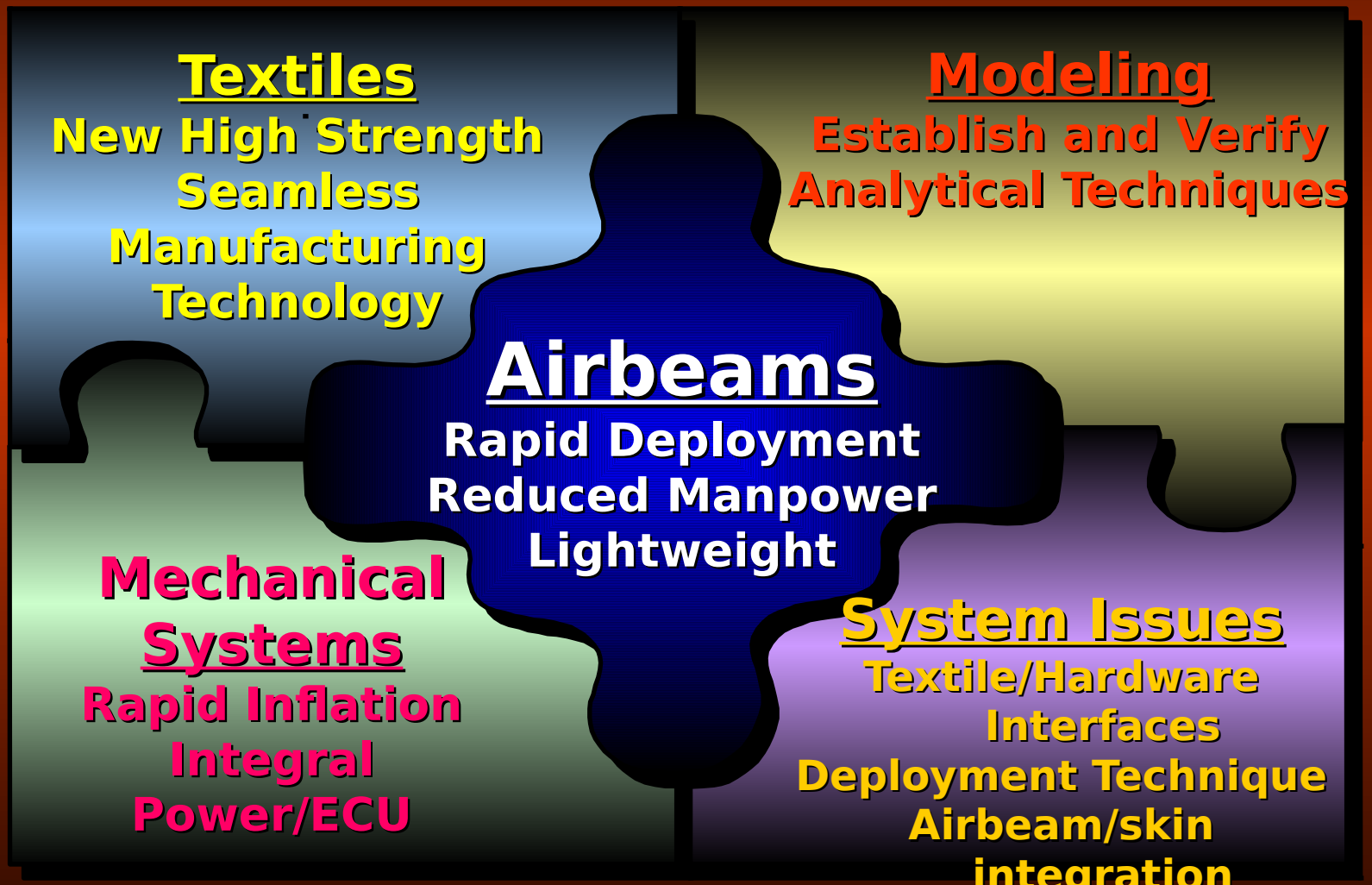

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Air Beam Structural Design

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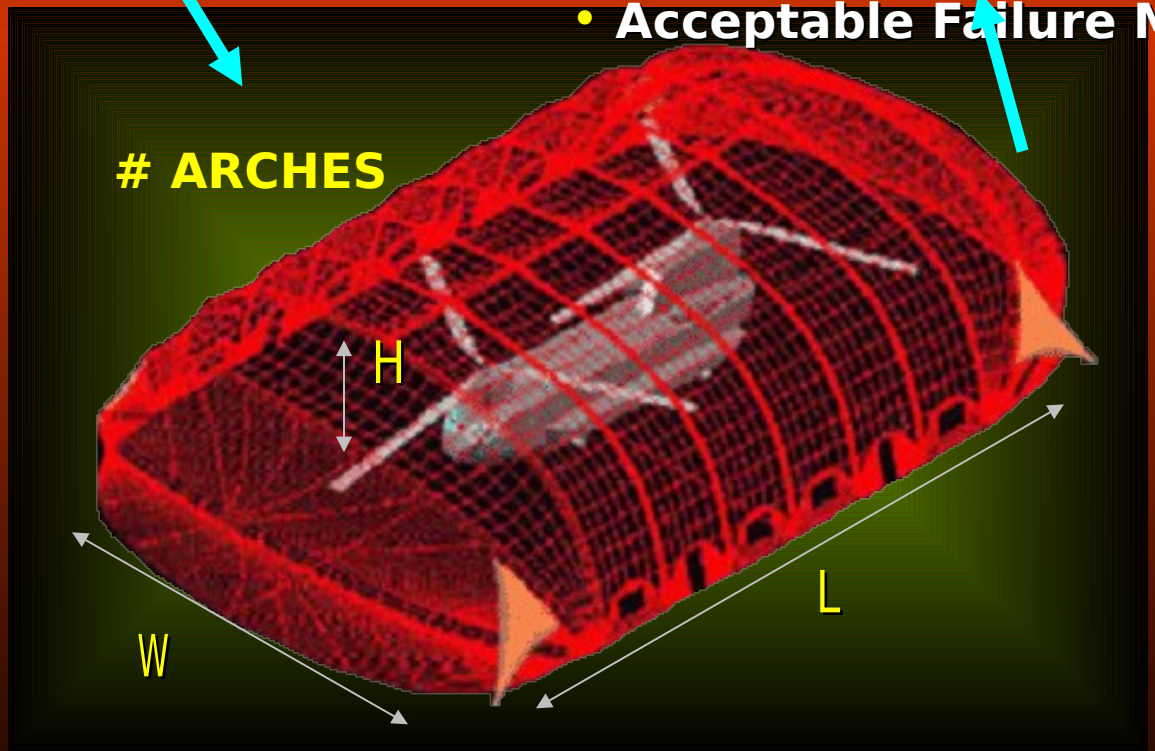
GIVEN

- Floor length & width
- Minimum height requirement
- Environmental Loadings

DETERMINE

- # Air beams / arches
- Diameter
- Safe operating pressure
- # Warp & weft tows per unit length
- Fiber material(s)
- Coating material
- Acceptable Failure Modes



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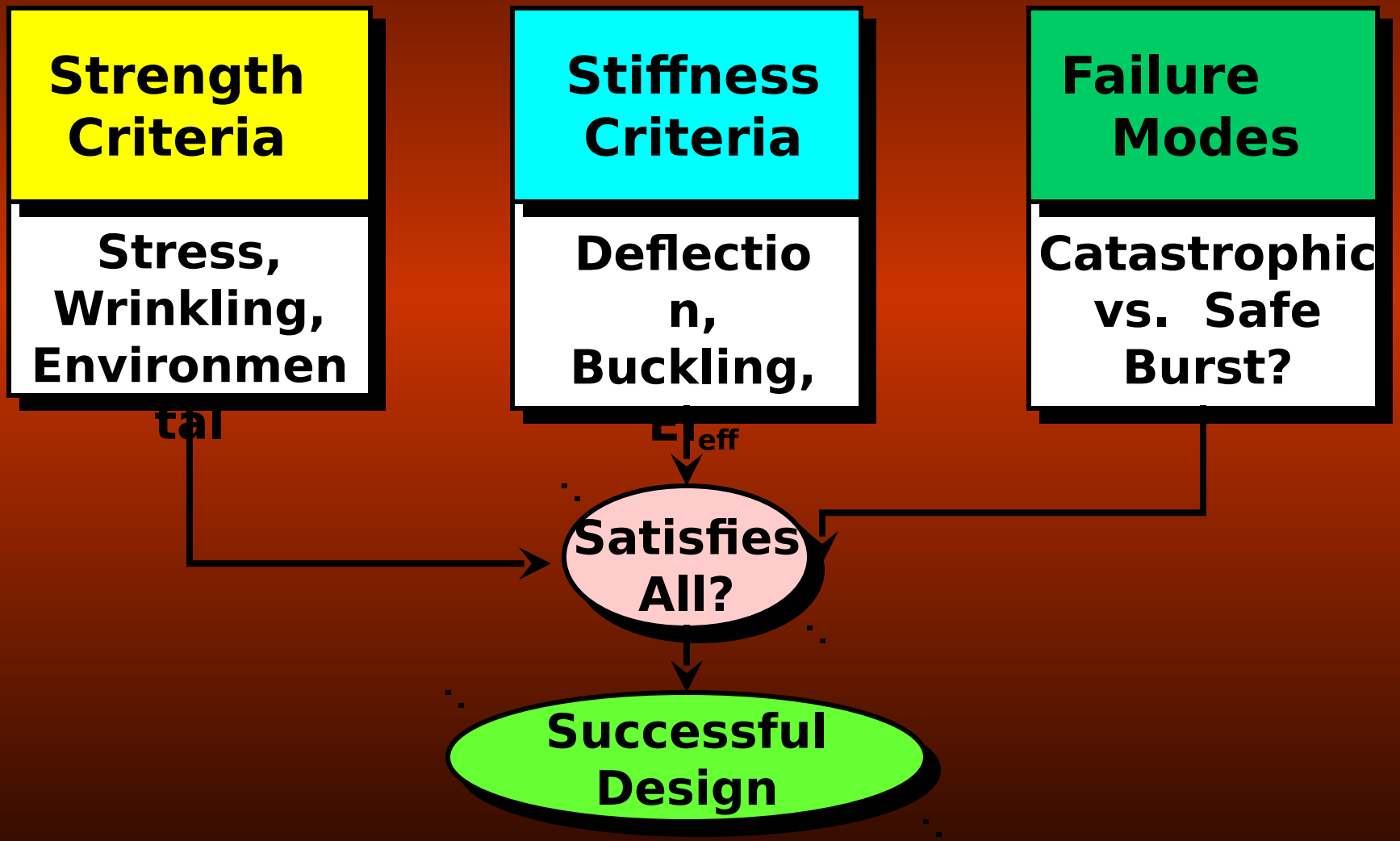
Structural Design Using Fabric Air Beams



PURPOSE

To Develop Predictive Performance Tools For Use in Designing Air Beam Supported Structures

Modeling Airbeam Structures

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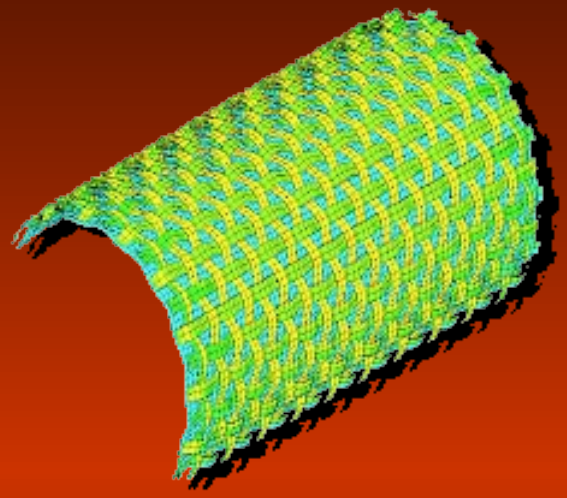
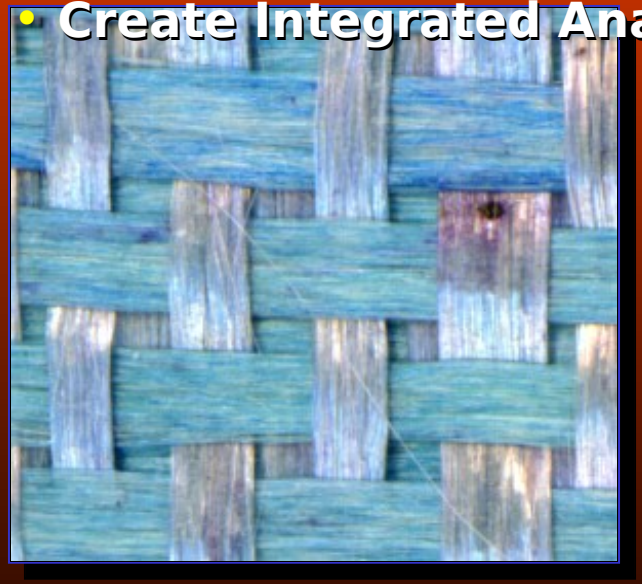
Modeling Goals

- Develop 3D Braiding & Weaving Models
- Scalable Verification Instrument
- Collect and Analyze Empirical Test Data
- Create Integrated Analytical To





Advantages

- Analyze Design Problems
- Technology Investment

Relevant Fabric Mechanics Research Topics

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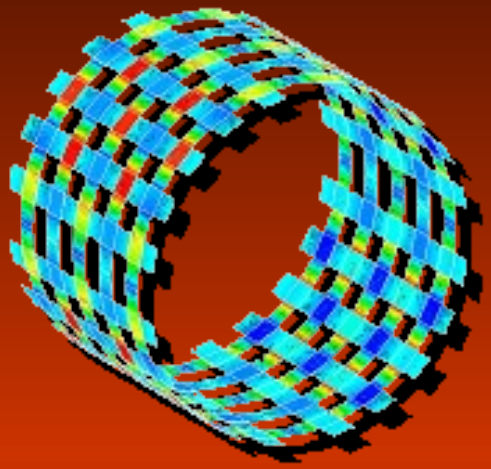
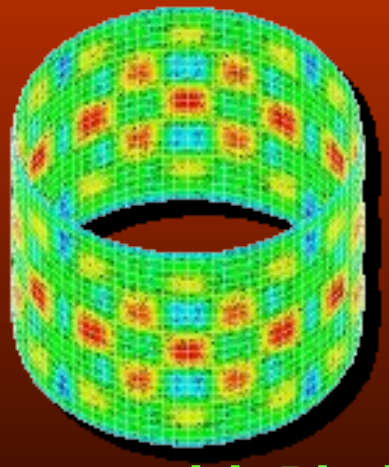


Air Beam without Bladder Shown



Air Beam with Bladder Shown

- Nonlinear membrane analysis w/ full tow-to-tow contact & friction capability
- Nonlinear fiber mechanics captured in local fabric strip model, represented in global structural model
- Anisotropic fabrics & hybrid fibers
- Bias angle effects on non-orthogonal (braided) fiber placements
- Determination of wrinkling onset and nonlinear flexural stiffness (E_{eff} x I)
- Effects of crimp, friction & coatings
- Fabric set from multiple

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4-Pt. Flexure Tests on Woven Vectran Air Beams

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4-Point Bend Fixture Mounted in Instron® with Displacement Wire Transducer Used To Capture Mid-Span Deflection (5 oz. constant tension force)

Construction Details

- 1500 denier Vectran & PEN
- 10 warps/inch
- 19 wefts/inch
- $Strength_{Vectran}$ = 28 gpd
- $Strength_{PEN}$ = 10 gpd
- Bladder: Estane 58315 TPU
- $Bladder_{thick}$ = 0.008”
- Coating: Neoprene/Urethane
- End Cap: Stitched-on

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Comparison of Vectran & PEN Air Beam Response

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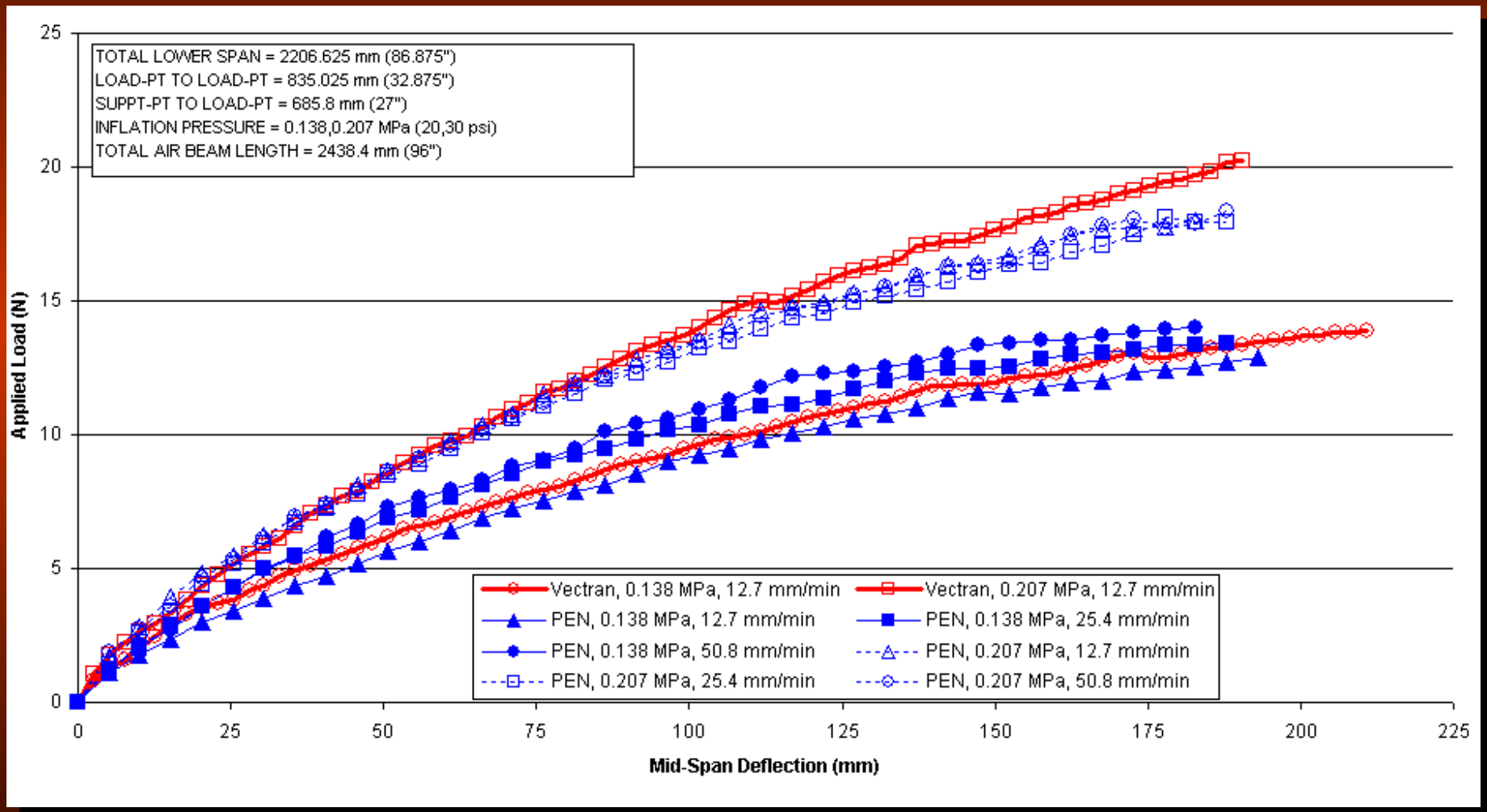

Note: Flexure response is invariant with tow modulus at these pressures.

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Comparison of Vectran® & PEN®

Tow Tensile Data

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Enlarged Image of Single

Tows are not a continuum

Instron® Fiber Testing

Vectran						
Test #	1500 Denier Fiber Type	Crosshead Rate (ipm)	Max Load (lbs)	Max Stress (psi	Max Strain (%)	Modulus (psi)
1	As Woven	0.5	52.0	269,156	2.3	1.17E+07
2	As Woven	1.0	50.5	261,392	2.0	1.31E+07
10	As Woven	2.0	63.8	330,234	2.2	1.50E+07
		AVG.——>	55.4	286,927	2.2	1.33E+07

PEN						
Test #	1500 Denier Fiber Type	Crosshead Rate (ipm)	Max Load (lbs)	Max Stress (psi	Max Strain (%)	Modulus (psi)
1	As Woven	0.5	17.8	92,134	3.8	2.42E+06
2	As Woven	1.0	17.6	91,099	4.0	2.28E+06
10	As Woven	2.0	19.2	99,381	3.8	2.62E+06
		AVG.——>	18.2	94,205	3.9	2.44E+06

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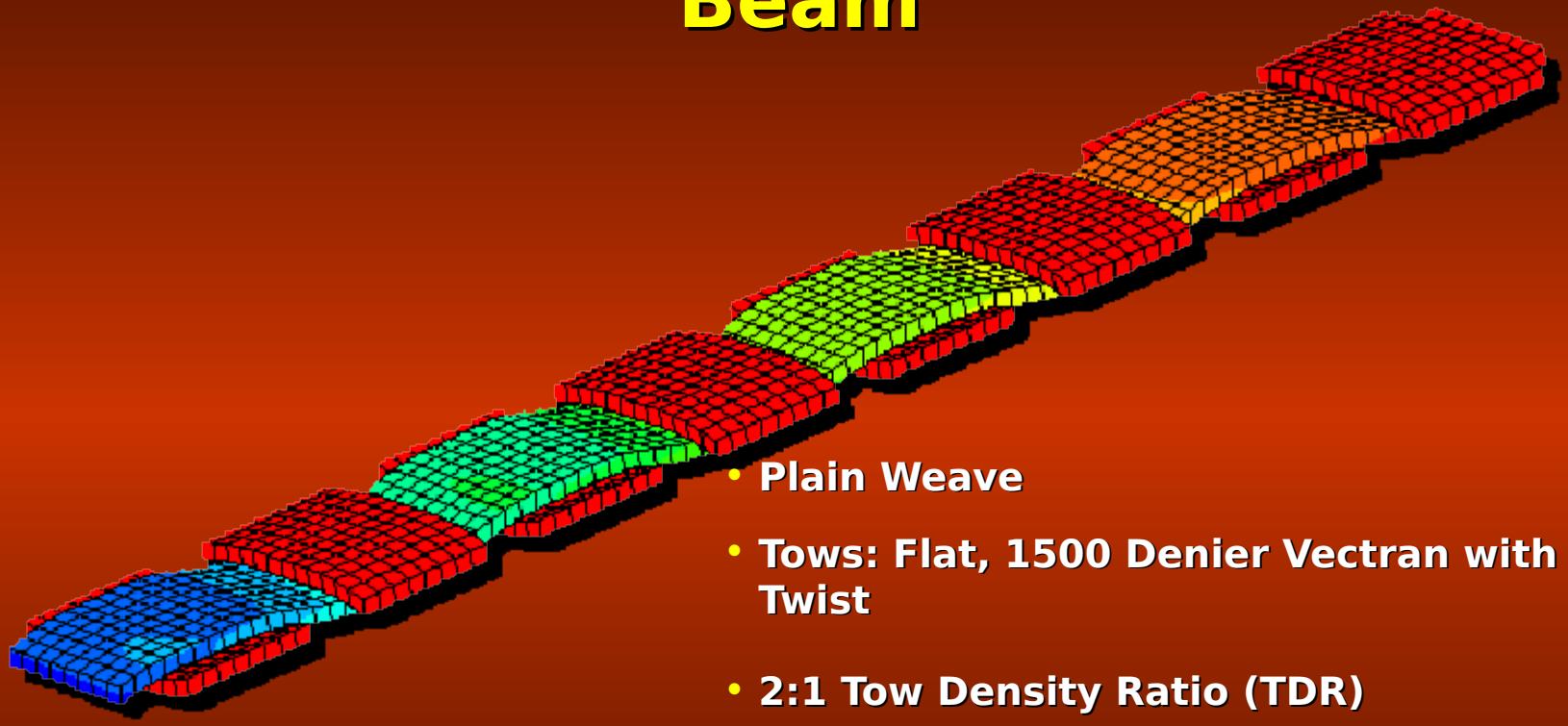
Fabric Strip Model of 1500 Denier 2 Inch Diameter Vectran Air Beam



- Plain Weave
- Tows: Flat, 1500 Denier Vectran with Zero Twist
- 2:1 Tow Density Ratio (TDR)
- 1:1 Biaxial Loading Ratio
- 10 Warps/Inch of Circumference
- 20 Wefts/Inch of Air Beam Length
- Coating: None

Modulus Predictions Using Fabric Strip Model for 2” Diameter 1500 Denier Vectran Air Beam

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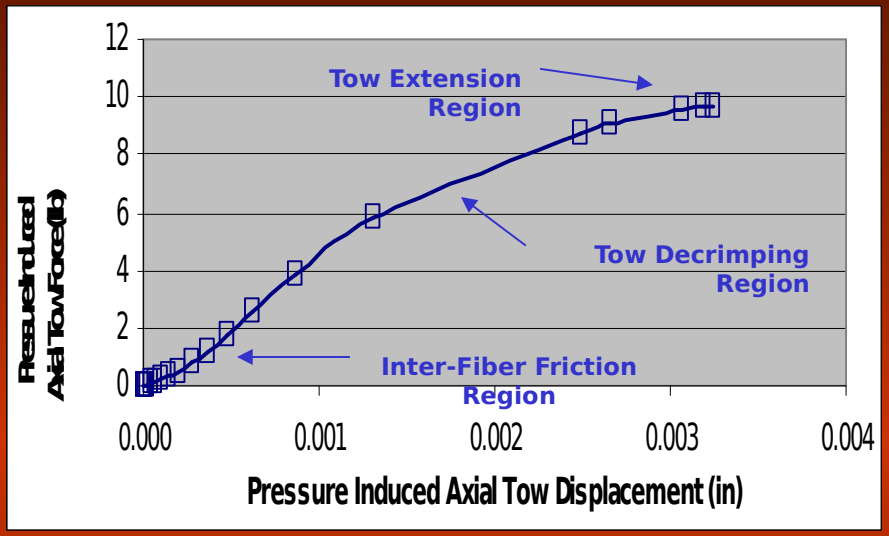
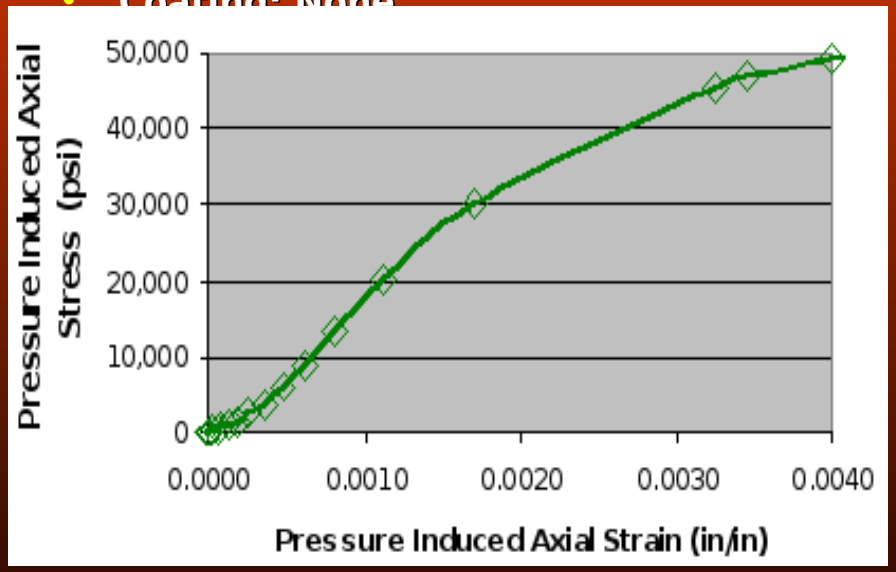
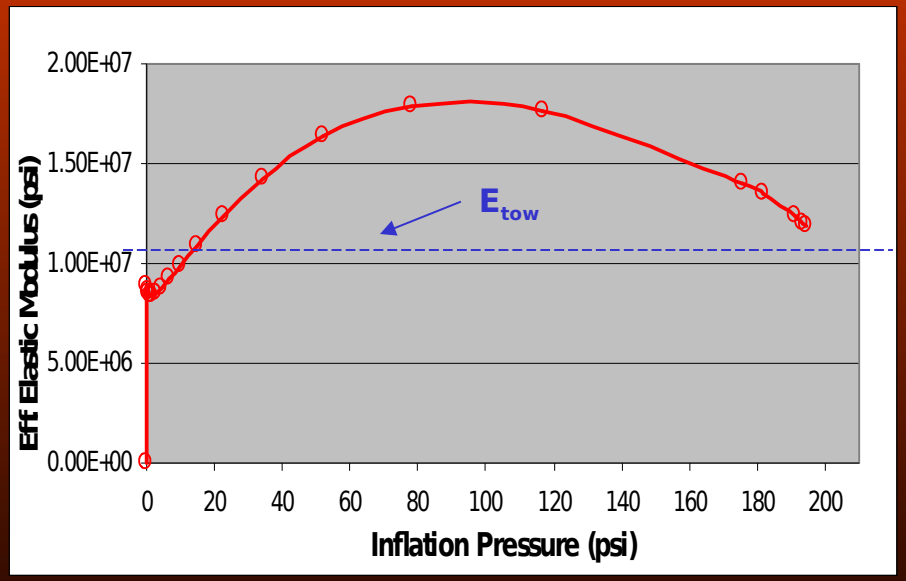
FABRIC DETAILS

- Plain Weave
- Tows: Flat, 1500 Denier Vectran with Zero Twist, E_{tow}=11.4Mpsi, 300 Filaments with 23 micron dia, Nominal Width = 0.0551”, Nominal Thickness = 0.00327”, Nominal Area = 0.00018 in²
- 2:1 Tow Density Ratio (TDR)
- 1:1 Biaxial Loading Ratio
- 10 Warps/Inch of Circumference, 20 Wefts/Inch of Air Beam Length
- Coating: None







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Summary

- **Inflated structures are an innovative technology with applications to the Army, Navy, and NASA.**
- **Modeling efforts are currently directed towards structural design and fabric optimization.**